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METHOD FOR CONTROLLING THE SPEED OF A VEHICLE

Background Information

The present invention is directed to a method for controlling the speed of a vehicle, particularly under consideration of vehicles driving ahead, in accordance with the definition of the species in the main claim.

From German laid open print DE 42 42 700 A1, it is known to mount a radar or infrared sensor on a vehicle to detect vehicles driving ahead. This radar sensor can be, for example, a module of a vehicle comfort and convenience system ACC (adaptive cruise control), in which information pertaining to the distance and the relative speed of the vehicle with respect to other vehicles and information on road conditions are continually processed.

The basic functions of the above described system relate to the control of the vehicle speed, either to a setpoint value, here the desired speed, or to the speed of a vehicle driving ahead, in the case that the latter is traveling at a slower speed than the desired speed and is within the sensing range of the radar sensor. As mentioned above, this sensor can be, for example, a component of a microwave radar or of an infrared lidar and, to that end, it measures the distance, the relative speed, and the angle of objects, particularly of vehicles driving ahead within the sensing range.

From German Patent DE 197 22 947 C1, a method is known, where, in addition to measuring the quantities described above, the ACC system also includes the future travel-course progression of the vehicle, along with the ACC system, in the control in order to determine the future travel corridor. For this, the future travel-course range of at least one vehicle driving ahead is determined, and a lateral offset is then ascertained for all detected vehicles. Given steady-state curvature conditions of the roadway, i.e., in a linear portion or in the region of constant curvature of a curve, the future travel corridor is also able to be easily

determined using the known method, with the aid of a well-adjusted yaw-rate or rotation-rate signal.

From the yaw rate of the ACC vehicle, the curvature of the roadway and, therefore, also the travel-course offset of a vehicle traveling ahead can be determined here, using generally known method steps. If this travel-course offset is smaller in terms of absolute value than a predefined width of the travel corridor, then one can infer that the vehicle traveling ahead is located in the travel corridor of the ACC vehicle. When working with changing conditions, particularly in the beginning curve region, however, one is normally no longer able to correctly determine the association with the travel corridor, so that it can happen that a vehicle driving ahead in the right, adjacent lane, near the beginning of a left curve, is incorrectly attributed to the travel corridor. This leads to faulty control reactions, the cause here being the mistaken curvature prediction, since the ascertained curvature is always specific to the current instant and, therefore, the reaction to a change in curvature is always too late.

Summary of the Invention

A method for controlling the speed of a vehicle of the type mentioned at the outset, where, in the vehicle to be controlled, the yaw rate or rotation rate is measured, in particular to determine the curvature of the vehicle's own travel trajectory, and where, using a proximity sensor or position sensor, at least one vehicle traveling ahead or at least some other object within a sensor's sensing range is detected with regard to an offset from the travel course of the vehicle to be controlled, is advantageously further refined in accordance with the present invention by the characterizing features of the main claim.

As already mentioned at the outset, curvature k of the roadway may be calculated in a simple manner from the measured yaw rate of the ACC vehicle to be controlled using generally known method steps in that the yaw rate is divided by the speed, and, using that, the travel-course offset y_c of a vehicle traveling ahead may also be determined. Specifically, travel-course offset y_c may be determined by the following formula:

$$y_c = y_v - k \cdot d^2 / 2,$$

quantity y_v being the measured lateral offset, without allowing for curvature k , and d being the distance between the vehicle to be controlled and the measured vehicle driving ahead.

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If this travel-course offset y_c is smaller in terms of absolute value than a predefined width y_{lane} , then one may infer that the object or the vehicle is located in the travel corridor of the ACC vehicle, y_{lane} corresponding approximately to one half of a lane width.

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In accordance with the present invention, travel-course offset y_c of a vehicle driving ahead, determined in preset measuring cycles, is delayed by a predefined time lag, and using the instantaneous curvature k of the travel trajectory of the vehicle to be controlled, a historical travel-course offset $y_{c_{hist}}$ is ascertained. In this context, the delay may advantageously be selected such that historical travel-course offset $y_{c_{hist}}$ is determined after approximately half of the distance between the vehicle to be controlled and the measured vehicle.

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Therefore, alternatively to the generally known method of looking ahead using video-based lane detection or navigational systems, the method according to the present invention for controlling an ACC vehicle permits, in a simple manner, a relatively fast and simple-to-implement historical comparison between the position and travel trajectory of the vehicles. Instead of a costly, continuous transformation of the measured data, the present invention provides, in simplified fashion, for measured lateral offset y_v to be delayed by about time span t_{hist} , commensurate with half of the time span between the vehicles.

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From this so delayed value $y_{v_{hist}}$, as above, using active curvature k , the so-called historical travel-course offset $y_{c_{hist}}$ is now determined in accordance with the relation:

$$y_{c_{hist}} = y_{v_{hist}} - k \cdot d_{hist}^2 / 2$$

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d_{hist} being generated or estimated, likewise on the basis of a delay, as the historical distance between the vehicle to be controlled and the measured vehicle. For example, in accordance

with the relation

$$d_{\text{hist}} = d_{\text{active}} - v_r * t_{\text{hist}}$$

- 5 Thus, distance d_{hist} takes into consideration the change in distance in response to speed differences. In illustrative terms, the mechanism functions as follows: the curvature determination is made approximately at the middle of the distance between the ACC vehicle and the measured object, although delayed by t_{hist} . Even when working with changing curvatures, the average curvature is a good estimation here and allows a quite precise
10 determination of travel-course offset.

To avoid unwanted transient effects in those cases where the object had not yet been measured for the length of time span t_{hist} and, consequently, no historical lateral offsets exist, it is advantageous when a dynamically increasing delay time $t_{\text{hist/dyn}}$ takes the place of time
15 t_{hist} , the time span until maximum value t_{hist} is reached being supplemented by the dynamic component that increases with the duration of observation. Until this maximum value is reached, the quality of the thus calculable yc_{hist} is somewhat lower, but this value is always ready as a transitional value.

20 In addition, a filtering is advantageous to compensate for short-term curvature fluctuations caused by steering motion or signal noise. Since this filtering likewise delays the active signal by t_{filter} , the delay in the y_v values must likewise last longer by approximately this value. The delay may be advantageously further modified, for example, by filter times of active curvature signal k . In this connection, the instantaneous value of curvature k of the travel
25 trajectory of the vehicle to be controlled, at any one time, is delayed by a preset value for averaging purposes, this delay being considered as well in the determination of historical travel-course offset yc_{hist} .

30 Although the delay times are known, so that t_{hist} is generated from the sum of half of the time gap and the filter time, such modifications of time span t_{hist} may be useful in order to achieve a functional optimum by way of a total adjustment. This applies, in particular, when the

quantities are not only filtered by a delay element, but are also averaged via low-pass-type filters. The latter is also used here for reducing measuring fluctuations. Delay element and averaging filter may be combined in simple fashion, for example, by using filters having a most constant possible group delay, e.g., Bessel filters or series-connected filters having a critical attenuation.

In summary, the method of the present invention enables historical travel-course offsets to be generated in simple fashion, in particular by combining averaging and delay, without necessitating a costly storing of lane data or transformation of such stored data. A rapid result is achieved, since one only has to wait for about half of the time gap up until the result.

To obtain a still further improved method for predicting the path of the vehicle to be controlled, it is also possible for a number of further detection devices for determining the travel-course offsets of objects traveling ahead to be present in the vehicle to be controlled. All results of these detection devices may then be analyzed and weighted. The analysis and weighting may preferably be carried out using a video camera, a preferably satellite-supported navigational system, a set-up for analyzing fixed destinations, or a set-up for determining a collective yaw or rotation rate of the objects driving ahead.

These and other features of preferred embodiments of the invention are derived from the claims, as well as from the specification and the drawings, it being possible for the individual features to be realized individually or multiply in the form of subcombinations in the specific embodiment of the present invention and in other areas, and to constitute advantageous and patentable embodiments, for which protection is claimed here.

Brief Description of the Drawing

The method according to the present invention for controlling the speed of a vehicle, under consideration of objects driving ahead, is elucidated on the basis of the drawing, whose figures show:

- Figure 1 a sketch of a curved roadway path, including a vehicle whose speed is to be controlled, and further objects;
- Figure 2 a sketch of a curved roadway path, including a vehicle whose speed is to be controlled, and further objects at various points in time;
- Figure 3 a diagram of the output signal of a delay-producing filter;
- Figure 4 an overview diagram of a lane probability with respect to objects located in a travel corridor;
- Figure 5 a diagram for assessing the various lane probabilities; and
- Figure 6 a block diagram relating to the analysis and weighting of various detection methods used to detect objects moving ahead.

Detailed Description

Figure 1 shows an ACC vehicle 1 to be controlled, which is located on a roadway 2 having a plurality of lanes. Vehicle 1 has, for example, a radar sensor 3 having a radar detection range 4; other detection set-ups are also mountable on vehicle 1, such as video or navigational devices, which may be used to detect roadway 2 or the area surrounding the roadway. Situated on roadway 2 as an object driving ahead is a vehicle 5, in reality, a plurality of such objects being present at various distances and at different speeds.

The ACC system in vehicle 1 includes a control system (not explained in further detail here) for influencing speed, and a plurality of sensors, such as a yaw-rate or rotation-rate sensor, a steering-angle sensor, wheel-speed sensors, or a transversal-acceleration sensor. A dot-dash line 6 represents the future desired travel-course progression, i.e., the travel trajectory of vehicle 1, and the two lines 7 show the future travel-course range or travel corridor. A line segment 9 indicates the lateral or travel-course offset of vehicle 5 driving ahead with respect

to the travel course of vehicle 1.

The assumption is made in the following, with reference to Figures 2 and 3, that, to correct the curvature of travel trajectory 6 of vehicle 1 in light of a curvature to be expected of roadway 2, a historical travel-course offset or lateral offset is used in the calculation.

In accordance with the exemplary embodiment illustrated in the drawing, travel-course offset y_c of a vehicle 8 driving ahead is delayed by a predefined time span, and using the then active curvature k , a historical travel-course offset $y_{c_{hist}}$ is determined at instants t_1 , t_2 , and t_3 of travel trajectory 6. In this context, the delay may advantageously be selected such that historical travel-course offset $y_{c_{hist}}$ is defined approximately at half of the distance between vehicle 1 to be controlled and vehicle 5 to be measured.

From this thus delayed value $y_{v_{hist}}$, so-called historical travel-course offset $y_{c_{hist}}$ is now determined, as above, using active curvature k , according to the relation

$$y_{c_{hist}} = y_{v_{hist}} - k \cdot d_{hist}^2 / 2.$$

Figure 3 shows a diagram of the output signal of a delay-producing filter. The time is shown in seconds on the horizontal axis, and the characteristic curve of an output signal is shown on the vertical without units/theoretically. The illustrated, exemplary characteristic curve shows a maximum of the output signal in the region of approx. 0.8 seconds. This maximum must be appropriately adapted to the desired delay.

The following describes a method for performing the previously described calculation, with the involvement of historical travel-course offset $y_{c_{hist}}$ for predicting a travel course. The selected abbreviations represent the common short forms of the corresponding physical quantities used for inputting into a data-processing system. For the sake of simplicity, the trajectory is assumed in this case to be a piece-wise constant parabola. The parabola curvature is defined approximately in the middle of the section between object 5 and vehicle 1 (compare Figure 2). Since the now single trajectory coefficient is defined already when the

middle is reached, a delay in the object lateral offsets y_v is also only necessary up to the middle. The time delay is achieved, for example, by a triply cascaded low-pass filter (not shown here) having a dynamic time constant T_{auy} for improving the transient response. Here, the following relations apply:

$$T_{auy}(t_j) = \text{MIN}(T_{auy}\text{Max}(t_j), T_{auy}\text{Max}(t_{j-1}) + T_{\text{cycle}});$$

in the case that a valid measured value exists for the object, otherwise it follows that

$$T_{auy}(t_j) = \text{MAX}(0, T_{auy}\text{Max}(t_{j-1}) - T_{\text{cycle}}/2)$$

where

$$T_{auy}(t_j)\text{MAX} = fT_{auyd} * (d(t_j)/v_{\text{Ref}}(t_j)) + fT_{auyKap} * T_{auKap}.$$

The filtering using the three low-pass stages yields a total group delay of $3T_{auy}(t_j)$. Thus, in three measuring cycles, one obtains the following lateral offsets:

$$y_{v1}(t_j) = (T_{\text{cycle}}/T_{auy}(t_j) * (y_v(t_j) - y_{v1}(t_{j-1})),$$

$$y_{v2}(t_j) = (T_{\text{cycle}}/T_{auy}(t_j) * (y_{v1}(t_j) - y_{v2}(t_{j-1})),$$

$$y_{v3}(t_j) = (T_{\text{cycle}}/T_{auy}(t_j) * (y_{v2}(t_j) - y_{v3}(t_{j-1})).$$

From output value $y_{v3}(t_j)$ of the filter, with the aid of trajectory curvature $k_{\text{Traj}}(t_j)$ (previously the value = k), the historical lateral offset to the middle of the course may be calculated as follows:

$$y_{\text{Hist}}(t_j) = y_{v3}(t_j) - k_{\text{Traj}} * (d(t_j) - v_r(t_j) * 3T_{auDy}(t_j))^2/2.$$

In this case, $v_r(t_j) * 3T_{auy}(t_j)$ corrects the active distance to historical reference point t_j -

3Tauy(t_j).

As a further characteristic quantity for the quality of the historical lateral offset, quantity ycHistQ is used; it is calculated from angular quality Qalpha (e.g. = 1) and from the observation duration for the calculation of the historical lateral offset:

$$ycHistQ(t_j) = \text{MIN}(1, ycHistQ(t_{j-1}) + Qalpha * T_{cycle}/TauHist(t_j))$$

$$T_{cycle}/TauHist(t_j)$$

respectively,

$$TauHist(t_j) = fTauHist * (d(t_j)/v_{Ref}(t_j)),$$

in the case that an object was measured, and a valid travel-course offset is at hand. Quantity fTauHist stands here for the fractional portion of the time gap, starting from which a steady-state performance is assumed. Otherwise, it holds that:

$$ycHistQ(t_j) = \text{MIN}(0, ycHistQ(t_{j-1}) - T_{cycle}/TauHist(t_j)).$$

Since the historical lateral offset is not available in sufficient quality until a relatively long waiting time has elapsed, on the basis of active lateral offset yv and the active travel-course curvature, an active travel-course offset yc_{Act} is determined, which is able to provide a lateral travel-course offset as soon as there is a first measurement of an object:

$$yc_{Act} = yv - yv_{Course} = Yv - d^2 * k_{Course}/2.$$

Figure 4 is a graphic representation illustrating the lane probability of the measured objects, active lane probability spwAct and historical lane probability spwHist following in parallel, in the same manner, for active lateral offset yc_{Act} and for historical lateral offset yc_{Hist}.

As is apparent from Figure 4, the basis of the previously mentioned lane probability determination is a surface having constant width L. Within this surface, a positive lane

probability is assigned, while outside of it, it becomes negative. The highest probability is assigned when yc is situated within the inner surface.

Similarly to the generally known fuzzy logic, the transitional region may be selected to be fuzzy, making it possible to determine a lane probability of -1 to + 1. The width of transitional region spw advantageously increases in response to a large distance.

A mixture of the described lane probabilities is shown in a diagram according to Figure 5. The two lane probabilities spwAct and spwHist are weighted as a function of the quality of historical lateral offset ycHistQ in the time Tauy and mixed to form a new value spw. Weighting factors f_{Act} and $f_{Act}+f_{Hist}$ from the diagram according to Figure 5 are generated as follows. f_{Hist} for ycHistQ is large in the case that the observation time corresponds approximately to TauyMax. f_{Act} may be constant or otherwise determined.

If, in this case, yc_{Act} and yc_{Hist} point to different travel lanes, then the values compensate for one another in accordance with the weightings f_{Act} and f_{Hist} . If, on the other hand, they are on the same lane, then they reinforce one another up to the maximum value $f_{Act} + f_{Hist}$.

Figure 6 shows a block diagram 40, which indicates various possibilities for detecting and evaluating object in travel-course progression k of an ACC vehicle, which may also be used in different combinations, individually or together. In left branch 41, a calculation is shown of a future travel-course progression by adding the vehicle's own trajectory from the vehicle's own yaw rate, to a collective yaw rate in a block 42. In a block 43, by consulting the active object data, a decision may now be made as to whether a detected vehicle is located in the vehicle's own calculated travel corridor and, therefore, comes under consideration as an object to which the vehicle's own speed should be adapted. If this is answered in the affirmative, the actual control may be carried out in a control system 44.

For this, in a parallel branch 45, it is intended for a video system 46 to be present, which likewise is able to define the vehicle's own travel corridor and detect an object driving ahead as a control object.

In a further branch 47, a navigational system 48 is provided, which, with knowledge of the vehicle's own position and, under consideration of existing map material, is able to effect the same control mechanisms as previously described.

- 5 In a further branch 49, in a module 50, a travel course prediction may be made for ACC vehicle 1, which, in the calculation, considers the previously described, historical, lateral offset between ACC vehicle 1 and a detected object (vehicle 5, 8).

- 10 In another parallel branch 51, in a module 52, a travel course determination may also be made using a travel-course offset ascertained by interpreting the position of fixed destinations, for example at the edge of the roadway.

- 15 In actual control system 44, by analyzing the results from the calculations of individual branches 41, 45, 47, 49, and 51, a final decision may now be made with respect to the selection of the vehicle driving ahead, if indicated, including a weighting of the individual results, to which the ACC vehicle adapts its speed.